BULLETIN OF MARINE SCIENCE, 53(2): 912–929, 1993

INDICES OF LARVAL BLUEFIN TUNA, *THUNNUS THYNNUS*, ABUNDANCE IN THE GULF OF MEXICO; MODELLING VARIABILITY IN GROWTH, MORTALITY, AND GEAR SELECTIVITY

Gerald P. Scott, Stephen C. Turner, Churchill B. Grimes, William J. Richards and Edward B. Brothers

ABSTRACT

Most indices of stock size for Atlantic bluefin tuna are fishery dependent, and thus do not benefit from statistical design. Alternatively, we derived a fishery independent index of western Atlantic stock size from ichthyoplankton surveys conducted by the National Marine Fisheries Service. The larval abundance indices developed from these surveys have been used to corroborate trends in fishery dependent estimates of stock size, as well as to tune the virtual population analysis. Estimates of average annual larval abundance at first daily increment formation per 100 m^2 sampled by oblique bongo tows were used to index total annual larval abundance. A model describing the observed mean trend in larva size at otolith daily increment count was developed to estimate a probability of age at length matrix for ageing the captured larvae. Daily loss rates (Z) were estimated through regression analysis of the larval catch curves. Effects of mesh size changes (333 μm or 505 μm) during the time series of sampling were incorporated into the estimates. Uncertainty in the index values for the various components of the estimator is incorporated through the delta method. Zero catch information from the sampling is incorporated through application of Pennington's transform. Finally, we tested several different methods of calculating the index to evaluate the sensitivity of the results to different assumptions.

Northern bluefin tuna, *Thunnus thynnus,* are a large (up to 304 cm and 679 kg) oceanic pelagic scombrid species that are found in the Atlantic and Pacific Oceans. Northern bluefin in the western Atlantic are found from Labrador and Newfoundland south into the Gulf of Mexico and the Caribbean Sea, and also off Venezuela and Brazil. In the eastern Atlantic, they occur from off Norway south to the Canary Islands, in the Mediterranean Sea and off South Africa (Collette and Nauen, 1983). Atlantic bluefin tuna are known to spawn in the Mediterranean Sea and in the Gulf of Mexico.

Most estimators of indices of stock size for Atlantic bluefin tuna are fishery dependent, and thus do not benefit from statistical design. Alternatively, we derived a fishery independent index of western Atlantic stock size from ichthyoplankton surveys conducted by the National Marine Fisheries Service. Larval abundance indices developed from these surveys (McGowan and Richards, 1986, 1987) have been used to corroborate trends in fishery dependent estimates of stock size, as well as to tune the virtual population analysis (McGowan and Richards, 1987; Anon., 1991).

In the eastern Atlantic Ocean and Mediterranean Sea bluefin tuna have been fished for thousands of years, while in the western Atlantic catches were not substantial until the 1960's when Japanese longline vessels and U.S. and Canadian purse seine vessels accounted for much of the catch (Anon., 1991). The highest catches were recorded in a brief period in the mid 1960's when substantial longline catches were taken off Brazil (Fig. 1); since that time very few bluefin tuna have been caught off Brazil.

Managers became concerned about the status of the stock during the late 1960's and early 1970's. The International Commission for the Conservation of Atlantic

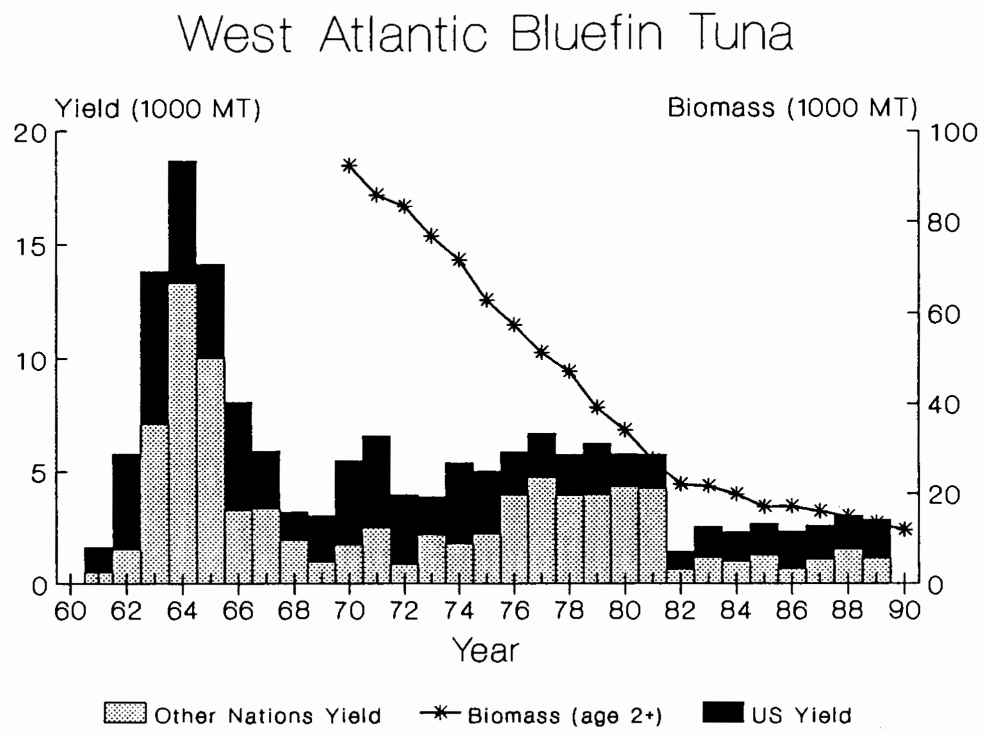


Figure 1. Yield time series and estimated stock biomass trajectory for western Atlantic bluefin tuna. Catch data since 1970 are those used in stock assessment analyses by the ICCAT Standing Committee on Research and Statistics. The biomass trajectory is that resulting from the 1990 SCRS west Atlantic bluefin tuna stock assessment.

Tunas (ICCAT) adopted a regulation to limit fishing mortality to recent levels in 1975. In 1982 ICCAT adopted: 1) an hypothesis of two management units of bluefin tuna with limited intermixing, one in the western Atlantic and the other in the eastern Atlantic and Mediterranean Sea; and 2) a catch restriction of 1,160 mt for the western Atlantic. The catch restriction was raised to 2,660 mt in 1983 and was maintained at that level until 1992, when a 10% reduction in the allowable harvest level was implemented. International assessments of the status of the western Atlantic bluefin resource, conducted annually by scientists from ICCAT member nations, have indicated a large decline in abundance (Fig. 1). Recently, the information used in those assessments has been restricted to the years since 1970 because of a shortage of observations on size composition for earlier years. Virtual population analysis (VPA) has been the primary stock assessment method, and indices of abundance from fishery catch rates or fishery independent surveys have been an integral part of those analyses.

Bluefin tuna larval assessment procedures were reviewed in 1989 by a NMFS review panel (Richards, 1990; Murphy, 1990). The NMFS peer review panel concluded that the larval index was useful for following trends in bluefin tuna abundance, while noting several problems that needed resolution. Some of the problems and questions identified by the reviews of Richards (1990) and Murphy (1990) have been or are currently being addressed, e.g., data management has been improved, processing of neuston samples is underway, the effect on the index of changing mesh size from 505 μm to 333 μm during the survey time series is being evaluated and the 1990 survey was continued through June to investigate the assumption made about duration of the spawning season. We recalculate the larval abundance index using revised methods.

METHODS

Survey Sampling and Data.—Ichthyoplankton surveys have been conducted in the Gulf of Mexico during April and May since 1977. Surveys in 1977–1981 covered much of the Gulf of Mexico (7.3–8.8 × 10^{11} m^2, Richards and Potthoff, 1980; McGowan and Richards, 1986), while surveys since then have concentrated on a smaller area (2.2–4.6 × 10^{11} m^2) within the northern and eastern Gulf of Mexico that consistently produced catches of larvae. Sampling was conducted both day and night with 61 cm bongo gear using oblique tows and 1 × 2 m neuston nets at stations at the intersection of whole degrees of longitude and latitude; additional tows (either bongo and neuston or just neuston) were made along the cruise track at 30-min intervals. From 1977–1981 one side of the bongo net was fished with a mesh of 333 μm and the other with 505 μm mesh; since 1982 both nets were 333 μm mesh. Through 1988 all samples were preserved in 10% formalin and transferred to 95% ethanol for long-term storage. Beginning in 1989, catches from one bongo and one neuston net at each station were preserved in that manner, and the other of each type in 95% ethanol so that the larvae could be aged. At each station, information was recorded on location, depth to the bottom, date, time of day, times of start and end of each tow, and the type of nets fished and the mesh in each net. Bongo nets were towed with a flow meter in one or both of the nets and the depth of tow recorded, as well as start and end flow meter readings.

Usually, one of the two bongo nets from each station was processed (sorted and identified). Bongo samples from 1977 and 1978 cruises were processed at the Southeast Fisheries Center. Since 1981, all selected samples preserved in formalin have been processed at the Polish Plankton Sorting and Identification Center in Szczecin, Poland. Each year all scombrid and scombrid-like fish identifications, as well as all unidentified fish, were reviewed by one coauthor (W.J.R.). Samples collected in 1989 and preserved in ethanol for ageing were not processed unless bluefin larvae were collected in the adjacent net (preserved in formalin). Improper preservation of some of these samples resulted in only 6 of 32 larvae being useful for ageing.

If more than one sample from a station was processed, only one sample per station was used in determining the larval catch and catch rate. For the 1977–1981 surveys only 505 μm samples were used because 333 μm samples were only occasionally sorted. For a few samples (<10) there was no flow meter data, in which case the flow meter data from the adjacent net on the same tow was used.

The data from the ichthyoplankton surveys were restricted to the area of the northern and eastern Gulf of Mexico that has been sampled in each survey (Fig. 2). This approach differs from that used in some other studies of various species in which a variable area is used in an attempt to account for annual differences in spawning area.

Ageing the Catch.—Because only the length of each larva was measured we developed procedures to age larvae from length. Data on daily otolith increments at length useful for describing larval growth were available from two sources. Brothers et al. (1983) reported on an analysis of length and daily increment counts for 369 larvae collected in 1981. Of these fish, both length and increment counts were reported for 317. Daily increment counts and length measurements were made on an additional six larvae collected during 1989 following the methods of Brothers et al. (1983). These otolith increment at length data were pooled for this analysis.

We modelled larval bluefin growth as a linear function over the observed range of data. First, the trend in mean length (L) was modelled as the linear regression of daily increment count (D) on L, fitted by least squares. Mean lengths at observed daily increment count for the regression were weighted by the inverse of the CV (L_D/SE_D, SE_D = standard error of length at D). For single observations within an increment count, SE_D was assumed equal to the observed length (i.e., a weight of 1 was assigned).

We developed a classification matrix (P(D | l), age-length key) from the linear growth model for use in ageing the larvae caught. We assumed that length at daily increment was distributed as a lognormal variate with variance computed as the deviation from the predicted values based on a least-squares linear regression through the origin where there was more than one observation at a given daily increment count (D). Based on the growth model, lognormally distributed random samples of 1,000 lengths for each predicted D (ranging from 1 to 11), with variance defined from the least-square function, were generated. From these simulated data, the proportions of the total number of lengths for each 0.1 mm length interval with a specific D value, were calculated and used as the elements of the P(D | l) classification matrix (i.e., estimates of the probability of age given length). Lengths less than 2.40 mm and greater than 9.99 mm were pooled into larger intervals (≤2.3 mm and ≥10.0 mm, respectively).

For comparison, we aged larvae by two methods, using the classification matrix and the linear model predicting D from mean L (following McGowan and Richards, 1987). From the classification

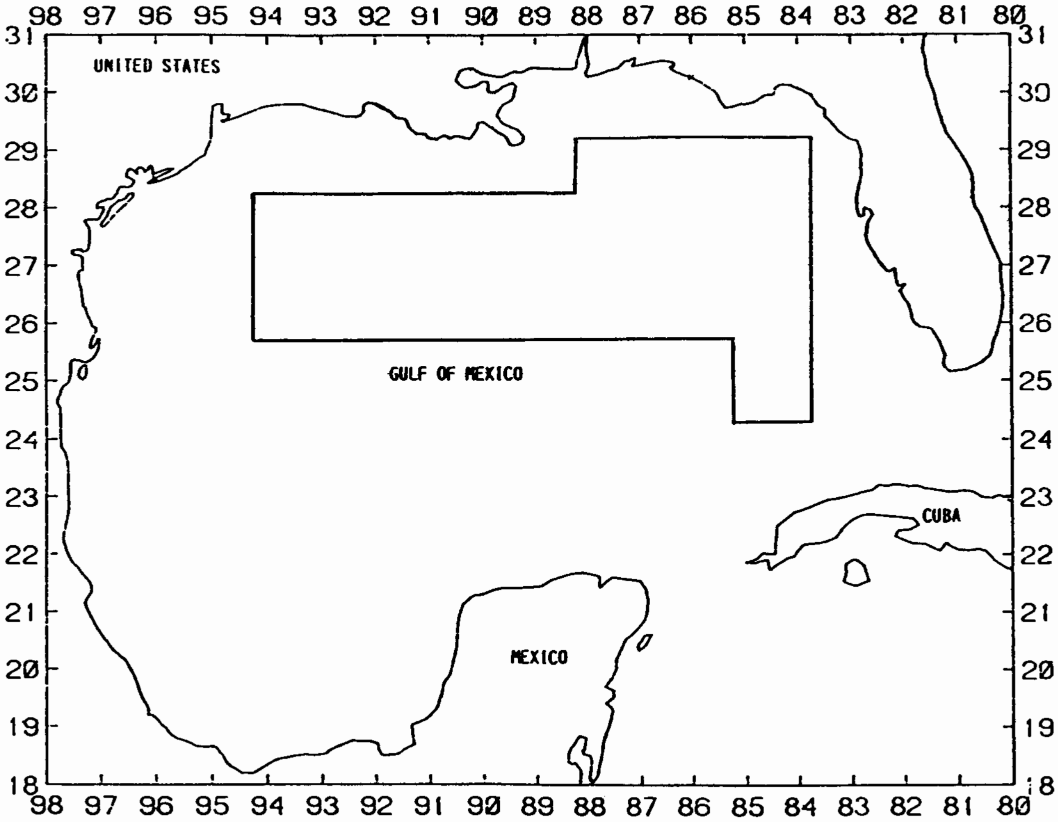


Figure 2. Map of the Gulf of Mexico showing the bluefin tuna larvae survey area. The area covers approximately 4.0×10^{11} m^2.

matrix, age (expected number of daily increments) of each larva for which we had length measures, was estimated as the sum of the product of D and the P(D | l) vector for the observed length. The variability in the expected daily increment count was taken as the variance of the corresponding P(D | l) vector. For the second method of ageing, we predicted age (daily increment number at length) using the linear growth model. The two methods were applied to the 538 measured larvae. The expected daily increment count for 14 larvae not measured was defined as the average for the sampling station where the larvae were collected.

Estimates of Z.—Because the survey catches were too small to support annual estimates of mortality, we used the expected daily increment counts generated using the classification matrix procedure to estimate daily larval loss (mortality) rates. Larval loss rates (Z, day^{-1}) were estimated as the slopes of linear regressions of the $\log_e$-transformed larval catch curve. Age-frequency data were pooled over years of the survey, but stratified by mesh size (i.e., 333 μm or 505 μm). The regressions were conducted over the range of expected daily increments frequencies from f_{max+1} to f_{10}, where f_{max} is the maximum daily increment frequency and f_{10}, the frequency for daily increment count 10 (the maximum observed count in the size at age data). The slopes of the regressions were used for estimates of Z. For this analysis, variability in Z was assumed equal to the asymptotic variance of the regression slope parameter.

Estimates of Relative Gear Efficiency.—Larval catch curves were used to estimate the relative efficiency of the two net mesh sizes and adjust the index for differences in gear efficiencies. The samples available for calculating the larval index were collected with 505 μm mesh nets from 1977 through 1981 and with 333 μm mesh nets from 1982 through the present.

Adjustment factors accounting for potential differences in gear efficiency were estimated in two ways. The first method employed the ratio of the cumulative frequencies at increment number (age) to adjust (i.e., raise) larval catches of partially recruited larvae. Daily increment-specific relative efficiencies of the 505 μm mesh for capture of small (i.e., partially recruited) larvae were estimated as the ratio (R^a_D) of the cumulative proportions of the daily increment frequencies of 333 μm relative to 505 μm for D's less than the assumed value of equal vulnerability to both mesh sizes.

$$R^a_D = \left(\frac{f_{3,D}}{\sum_{D=1}^{e} f_{3,D}}\right) \bigg/ \left(\frac{f_{5,D}}{\sum_{D=1}^{e} f_{5,D}}\right) \tag{1}$$

where D indexes daily increment number, e is the D value of assumed equal vulnerability to both gears, 5 indicates 505 μm and 3 indicates 333 μm mesh size.

For the second procedure, we employed catch-curve regressions for each mesh size to predict expected frequencies of the partially recruited increment counts (ages), then used the ratio of the expected to the observed frequencies to adjust (raise) the observed frequencies of the partially recruited ages for each mesh size. Specifically, daily increment-specific mesh efficiencies were estimated for partially recruited larvae to either gear as the ratio ($R^b_{D,g}$) of the expected increment frequencies, given an assumed Z, to the observed frequencies.

$$R^b_{D,g} = e^{-Z(r-D)}\left(\frac{f_{r,g}}{f_{D,g}}\right) \tag{2}$$

where g (=3, 5) indicates mesh size and r is the D value for fully recruited larvae.

To examine the effect of variability in the $R^b_{D,g}$ adjustment factor on the overall index uncertainty, the gear specific catch curves were bootstrapped with 500 iterations and the assumed Z allowed to randomly vary from a normal distribution with mean equal to the gear-specific Z, and a variance equal to the variance in Z estimation from the regression analysis described above (i.e., equal to the asymptotic variance of the regression slope parameter).

Larval Index Estimates.—We estimated the mean number of larvae per 100 m^2 at first daily increment formation for each sampling station for each year of the time series and used it to index total abundance. These were estimated as:

$$I_{s,y} = \frac{\sum_{i=1}^{k} R_D e^{-Z(D_{s,y,i}-1)}}{A_{s,y}} \tag{3}$$

where y indexes year, s indexes sampling station, i (=1, . . . , k) indexes individual larvae, A, the surface area sampled, and R_D, the gear efficiency estimate applied. $I_{s,y}$ was estimated using four different combinations of parameters: a) Using the linear growth model to age the larval catch and no gear efficiency adjustment; b) Using the classification matrix to age the catch and no gear efficiency adjustment; c) Using the classification matrix to age the catch and the ratio of cumulative frequencies at age method (equation 1) to adjust for differing gear efficiencies; and d) Using the classification matrix to age the catch and the difference between observed and expected frequency at age method (equation 2) to adjust for differing gear efficiencies. Variability in $I_{s,y}$ was estimated using the delta method (Seber, 1983), assuming independence between the product terms, as follows:

$$V(I_{s,y}) = \frac{1}{A_{s,y}^2}\left[\sum_{i=1}^{k} e^{-Z(D_{s,y,i}-1)}\{V(R_{D,i}) + (Z_i^2V(Z_i) + (1 - D_{s,y,i})^2V(D_{s,y,i}))R_{D,i}^2\}\right] \tag{4}$$

We estimated average annual larval density, I_y, taken to be the annual index value, and the variability in the index due to among station effects ($V(I_{\Delta,y})$) from the station sample mean and variance of the $\log_e$-transformed $I_{s,y}$ estimates using the Δ-distribution method (Pennington, 1983). Thus,

$$I_y = \frac{m_y}{n_y} e^{T_y} G_{m_y}\left(\frac{s_y^2}{2}\right), \tag{5}$$

where m_y is the number of stations sampled with larvae, n_y the total number of stations, T_y and s_y^2 the sample mean and variance of the m_y $\log_e$-transformed $I_{s,y}$ values, and

$$G_{m_y}\left(\frac{s_y^2}{2}\right) = 1 + \frac{m_y - 1}{m_y}\left(\frac{s_y^2}{2}\right) + \sum_{j=2}^{\infty} \frac{(m_y - 1)^{2j-1}}{m_y^j(m_y + 1)(m_y + 3)\dots(m_y + 2j - 3)} \frac{\left(\frac{s_y^2}{2}\right)^j}{j!}. \tag{6}$$

A convergence criterion of 0.001 was used in calculating this series. The estimate of among station variance ($V(I_{\Delta,y})$) from the Δ-distribution method (Pennington, 1983) takes the form:

$$V(I_{\Delta,y}) = \frac{m_y}{n_y} e^{2T_y}\left[\frac{m_y}{n_y} G_{m_y}{}^2\left(\frac{s_y^2}{2}\right) - \left(\frac{m_y - 1}{n_y - 1}\right) G_{m_y}\left(\frac{m - 2}{m - 1} s_y^2\right)\right]. \tag{7}$$

Table 1. ANOVA results for the linear trend in mean length (LBAR) with daily increment count (D). Also shown are the weights, model predictions and residuals from the fit

Dependent Variable: Daily Increment

Analysis of variance

Source	DF	Sum of squares	Mean square	*F* value	Prob > *F*
Model	1	575.90065	575.90065	82.440	0.0001
Error	7	48.90012	6.98573		
C total	8	624.80077			
Root MSE		2.64305	*R*-square	0.9217	
Dep mean		6.02501	Adj *R*-sq	0.9106	
CV		43.86802			

Parameter estimates

Variable	DF	Parameter estimate	SE	T for H_0: Parameter = 0	Prob > |T|
INTERCEP	1	−5.557875	1.30777739	−4.250	0.0038
LBAR	1	2.491423	0.27439713	0.080	0.0001

Weight	Dep var D	Predict value*	SE predict*	Lower 95% mean*	Upper 95% mean*	Lower 95% predict*	Upper 95% predict*	Residual
18.7667	2.0000	1.5842	0.568	0.2422	2.9262	−0.3862	3.5546	0.4158
1.0000	3.0000	4.8613	0.315	4.1161	5.6064	−1.4329	11.1554	−1.8613
1.0000	4.0000	5.6784	0.290	4.9918	6.3651	−0.6090	11.9659	−1.6784
14.3703	5.0000	6.4275	0.291	5.7388	7.1163	4.6408	8.2143	−1.4275
10.2606	6.0000	6.0154	0.288	5.3346	6.6961	3.9489	8.0818	−0.0154
12.1117	7.0000	6.7229	0.298	6.0183	7.4274	4.7938	8.6520	0.2771
7.7728	8.0000	7.7559	0.345	6.9394	8.5723	5.3701	10.1416	0.2441
7.1805	9.0000	8.8453	0.424	7.8439	9.8468	6.3071	11.3836	0.1547
11.8367	10.0000	9.1515	0.449	8.0902	10.2128	7.0476	11.2554	0.8485

* Model predicted mean D, estimated standard error of predicted mean D, lower and upper 95% confidence interval bounds for model predicted mean D (accounts for variation in the parameter estimates only), lower and upper 95% confidence interval bounds for predicted D (accounts for variation in the parameter estimates and includes variation due to the model error term).

Since sampling was conducted in a two-stage fashion, the overall variance about I_y was calculated as the weighted sum of the Δ-distribution variance, which incorporates the variable proportion of zero catch information into the estimate as well as inter-station variability for the positive catch stations from equation (7), and the variability contributed by uncertainty within a station due to ageing and gear effects as estimated from equation (4). Thus, overall variability in the estimate was taken as:

$$V(I_y) = \left(\frac{n_y}{N_y}\right)\frac{\sum_{s=1}^{n_y} V(I_{s,y})}{n_y^2} + \left(1 - \frac{n_y}{N_y}\right)V(I_{\Delta,y}), \tag{8}$$

where N represents the total possible number of stations in the study area. Since the number of possible stations in the study area is very large compared to the number sampled, the weight given to the within station term is negligible and the overall variance is approximated by the among station term ($V(I_{\Delta,y})$).

Results and Discussion

The inverse of the growth model we developed to age bluefin tuna larvae predicts age from length. The ANOVA of the linear regression of mean length at daily increment count (Table 1) indicates that the relationship is highly significant over the range of observed lengths (1.7–8.4 mm). The poor fit of the trend to single data points is appropriate (increment numbers 3 and 4), and resulted from the weighting procedure (Fig. 3).

Information on the variability in the distribution of length about age was used in developing the age classification matrix. Because sufficient observations were

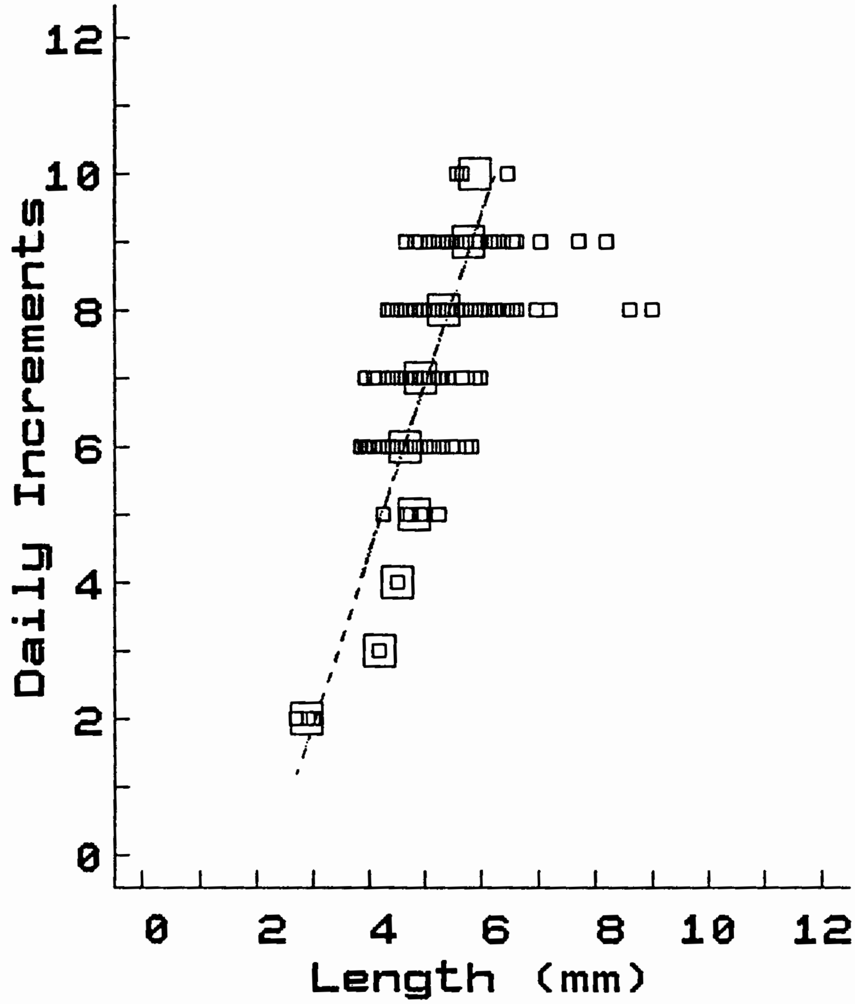


Figure 3. Linear bluefin larval growth model describing daily increments at length as a linear function of observed mean length. Small squares represent observations and large squares are mean values.

not available for lengths about all ages of interest, this variance was estimated from a regression. The linear regression of sample precision (CV) of mean length on observed mean length (Table 2) provided a basis for estimating this variability over a range of mean lengths at age. The regression was used to predict the variability in mean length at age for daily increment counts 1–11. The modelled probability of length at daily increment is shown in Figure 4. Random samples of 1,000 lengths from each lognormal distribution of length about ages 1–11 was used to estimate the probability of daily increment count for a given length interval. These estimates resulted from the proportion of the total number of simulated lengths for each daily increment count for each 0.1 mm length increment over the range ≤2.3–≥10.0 mm. The daily increment at length classification matrix, P(D | l), constructed from the model simulated samples are shown in Table 3. The method used to construct the P(D | l) matrix implicitly assumes a prior distribution of D that is uniform. Alternative assumptions about the prior distribution of D might result in different estimates of P(D | l), however the imprecision in the larval density estimates is such that differences resulting may

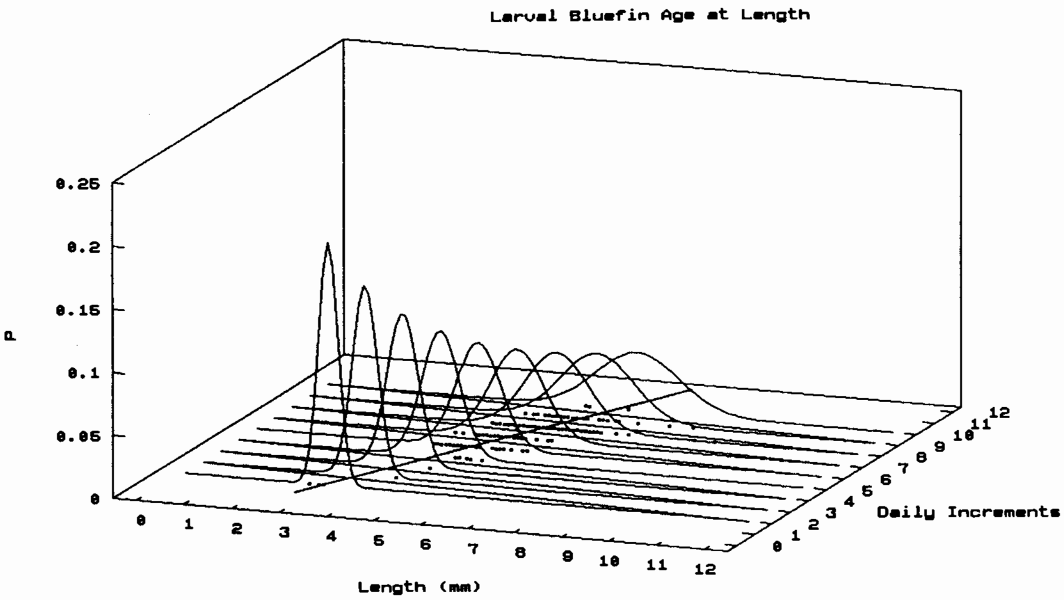


Figure 4. The modelled probability (P) of length at daily increment. Curves represent the probability surface; the observations (data points) and linear trend (solid line) are also shown.

be undetectable (e.g., compare index values resulting from methods a and b in Table 5 and Fig. 6).

The gear-specific catch curves we developed are similar (Fig. 5). Larvae were assumed fully recruited to the 333 μm mesh at 2 daily increments, while a value of 3 daily increments was used for the 505 μm mesh. Regression analysis to estimate Z for each gear ranged over values of 3–10 daily increments for 333 μm and from 4–10 for the 505 μm mesh (Table 3). Differences in gear-specific Z estimates could mean that the total loss rate is mesh-specific, indicating a need to include a factor in equation (2) to account for a mesh effect on Z. However, as evidenced by these results, the Z estimates by gear are not appreciably different, each gear type having an estimated Z of 0.2 day^{-1}, and including a gear term in

Table 2. ANOVA results and model parameter estimates from the linear regression of sample precision of mean length (CV) on observed mean length (LBAR)

Dependent Variable: CV

Analysis of variance

Source	DF	Sum of squares	Mean square	F value	Prob > F
Model	1	44,116.06884	44,116.06884	327.698	0.0001
Error	6	807.74484	134.62414		
U total	7	44,923.81368			
Root MSE		11.60276	R-square	0.9820	
Dep mean		11.40907	Adj R-sq	0.9790	
CV		101.69769			

Parameter estimates

Variable	DF	Parameter estimate	SE	T for H_0: Parameter = 0	Prob > |T|
LBAR	1	2.220043	0.12263784	18.102	0.0001

Table 3. The classification matrix for ageing bluefin larvae derived from 1,000 random samples per length class (LCASS) given the model specified mean length at daily increment count. LCLASS is equivalent to length in mm times 10. P1, P2, . . . , P11 represent the estimated P(D|l) values

LCLASS	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11
23	1.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
24	0.96479	0.03521	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
25	0.95492	0.03279	0.00410	0.00820	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
26	0.87879	0.11742	0.00379	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
27	0.69498	0.27799	0.02317	0.00000	0.00386	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
28	0.40316	0.53755	0.05138	0.00395	0.00395	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
29	0.12774	0.72993	0.12409	0.01460	0.00000	0.00000	0.00000	0.00365	0.00000	0.00000	0.00000
30	0.02682	0.75096	0.18008	0.02299	0.00766	0.00383	0.00766	0.00000	0.00000	0.00000	0.00000
31	0.00727	0.59273	0.32364	0.06182	0.01091	0.00364	0.00000	0.00000	0.00000	0.00000	0.00000
32	0.00402	0.35743	0.48996	0.10040	0.02008	0.00803	0.00803	0.00402	0.00402	0.00402	0.00000
33	0.00000	0.25506	0.51417	0.16194	0.04049	0.01619	0.00810	0.00000	0.00000	0.00405	0.00000
34	0.00000	0.10744	0.56612	0.24380	0.04545	0.02479	0.00413	0.00000	0.00000	0.00000	0.00826
35	0.00000	0.02652	0.56439	0.28030	0.09848	0.01894	0.00379	0.00000	0.00379	0.00000	0.00379
36	0.00000	0.01449	0.42754	0.36957	0.11594	0.04710	0.01449	0.00725	0.00000	0.00000	0.00362
37	0.00000	0.00000	0.25461	0.47232	0.18081	0.05904	0.01476	0.00738	0.00369	0.00369	0.00369
38	0.00000	0.00000	0.15753	0.44521	0.28425	0.06507	0.01712	0.00685	0.00000	0.00000	0.02397
39	0.00000	0.00000	0.06985	0.43015	0.30882	0.11029	0.02941	0.01838	0.00368	0.01103	0.01838
40	0.00000	0.00000	0.04412	0.35662	0.36765	0.14338	0.03309	0.02206	0.01471	0.00368	0.01471
41	0.00000	0.00000	0.02893	0.25207	0.38430	0.17355	0.11157	0.02479	0.00826	0.01240	0.00413
42	0.00000	0.00000	0.01111	0.18889	0.37037	0.22963	0.09630	0.04815	0.02963	0.00370	0.02222
43	0.00000	0.00000	0.00000	0.15152	0.33712	0.24242	0.16288	0.04924	0.00758	0.01136	0.03788
44	0.00000	0.00000	0.00000	0.08696	0.31884	0.28623	0.13406	0.07246	0.03986	0.01449	0.04710
45	0.00000	0.00000	0.00000	0.04508	0.22541	0.31148	0.20492	0.09016	0.05738	0.02869	0.03689
46	0.00000	0.00000	0.00000	0.01859	0.21561	0.30112	0.18959	0.11152	0.05948	0.04089	0.06320
47	0.00000	0.00000	0.00000	0.01498	0.17228	0.25468	0.26592	0.12360	0.08614	0.02996	0.05243
48	0.00000	0.00000	0.00000	0.00355	0.09929	0.26596	0.26241	0.15603	0.07447	0.04255	0.09574

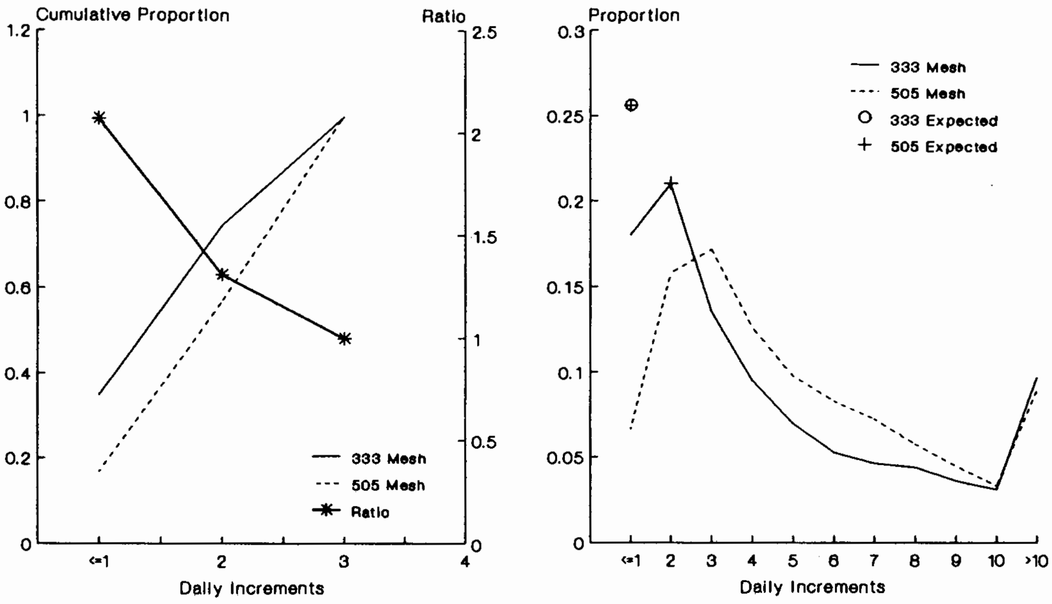
Table 3. Continued

LCLASS	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11
49	0.00000	0.00000	0.00000	0.00000	0.05204	0.24164	0.28625	0.17100	0.08178	0.06320	0.10409
50	0.00000	0.00000	0.00000	0.00356	0.01423	0.20285	0.32740	0.19929	0.11388	0.04626	0.09253
51	0.00000	0.00000	0.00000	0.00000	0.03226	0.22581	0.22581	0.19713	0.15412	0.06093	0.10394
52	0.00000	0.00000	0.00000	0.00000	0.02622	0.17603	0.20974	0.17978	0.14232	0.11610	0.14981
53	0.00000	0.00000	0.00000	0.00000	0.00746	0.11567	0.21269	0.25746	0.16791	0.07836	0.16045
54	0.00000	0.00000	0.00000	0.00000	0.00373	0.05970	0.21642	0.23134	0.17164	0.13433	0.18284
55	0.00000	0.00000	0.00000	0.00000	0.00000	0.04851	0.14925	0.19403	0.19030	0.15672	0.26119
56	0.00000	0.00000	0.00000	0.00000	0.00000	0.02491	0.14947	0.24199	0.18505	0.13167	0.26690
57	0.00000	0.00000	0.00000	0.00000	0.00000	0.02703	0.09459	0.19820	0.25676	0.13063	0.29279
58	0.00000	0.00000	0.00000	0.00000	0.00000	0.02672	0.10687	0.16794	0.21374	0.17176	0.31298
59	0.00000	0.00000	0.00000	0.00000	0.00000	0.01132	0.06038	0.16226	0.20377	0.18491	0.37736
60	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.04741	0.16379	0.18966	0.18103	0.41810
61	0.00000	0.00000	0.00000	0.00000	0.00000	0.00820	0.02459	0.13525	0.19672	0.20492	0.43033
62	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00800	0.14800	0.20800	0.14800	0.48800
63	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.03043	0.09130	0.19565	0.21304	0.46957
64	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00952	0.08571	0.16190	0.16190	0.58095
65	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.01310	0.07424	0.11790	0.18777	0.60699
66	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00985	0.04433	0.12315	0.24138	0.58128
67	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00442	0.04867	0.11504	0.19912	0.63274
68	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00437	0.02620	0.07424	0.19651	0.69869
69	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.03846	0.07692	0.17582	0.70879
70	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.03723	0.07979	0.12234	0.76064
71	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.02970	0.05941	0.11386	0.79703
72	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00549	0.05495	0.14286	0.79670
73	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.01117	0.05028	0.10056	0.83799
74	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.01818	0.13333	0.84848

Table 3. Continued

LCLASS	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11
75	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.03681	0.04908	0.91411
76	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.03226	0.10323	0.86452
77	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00719	0.03597	0.95683
78	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00826	0.04132	0.95041
79	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.01563	0.07813	0.90625
80	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.05147	0.94853
81	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00806	0.02419	0.96774
82	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.05333	0.94667
83	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.03361	0.96639
84	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.01064	0.00000	0.98936
85	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00971	0.00000	0.99029
86	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	1.00000
87	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	1.00000
88	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	1.00000
89	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.01471	0.98529
90	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	1.00000
91	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	1.00000
92	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	1.00000
93	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.02326	0.97674
94	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	1.00000
95	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	1.00000
96	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.02083	0.97917
97	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	1.00000
98	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	1.00000
99	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	1.00000
100	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	1.00000

Notes: P1 represents daily increment counts of 1 or less; P11 represents daily increment counts of 11 or more. LCLASS 23 represents lengths ≤2.3 mm; LCLASS 100 represents lengths ≥10.0 mm.



(a) (b)

Figure 5. (a) Gear-specific catch curves for bluefin tuna larvae in survey samples, and expected proportions of partially recruited ages for each mesh size that were backcalculated by regression using an assumed constant slope (Z) of -0.2. (b) The cumulative proportion of larvae caught by gear over the range of 1–3 daily increments and the adjustment ratio computed based on the method described in the text.

equation (2) was judged unnecessary for this application. The value estimated for Z (i.e., $0.2 \cdot \text{day}^{-1}$) falls in the range cited in Houde (1989), who reviewed daily larval mortality rates for many species. We felt the value estimated was reasonable and appropriate to use in subsequent analyses. To characterize the variability in the larval density estimates attributed to gear, we used the gear-specific Z's and associated asymptotic standard errors (Table 4).

The two alternative adjustments to the larval index (I_y) for different sampling gear efficiencies (i.e., 333 μm vs. 505 μm mesh) gave somewhat different results. Cumulative proportions for the gear-specific catch curves for larvae estimated to have 3 or fewer daily increments are, as expected, higher for the smaller (333 μm) mesh (Fig. 5b). Assuming equal vulnerability to the gear at $e = 3$ daily increments, this method estimated that the relative efficiency of the 505 μm mesh is 48% for larvae with one or fewer expected daily increments and 76% for larvae with 2 expected daily increments. These relative efficiencies correspond to adjustment values of $R^a_1 = 2.07$ and $R^a_2 = 1.31$. In the second method, we predicted the expected proportion for each gear, given an assumed constant Z of $-0.2 \cdot \text{day}^{-1}$ for the 333 μm and 505 μm mesh catch curves (Fig. 5a). For the 333 μm mesh, with an assumed $r = 2$, the observed proportion at one daily increment is 70% of the expected ($R^b_{1,3} = 1.42$). For the 505 μm mesh, the adjustment values when $r = 3$ are $R^b_{1,5} = 3.87$ (26% of expected) and $R^b_{2,5} = 1.33$ (75% of expected). Variability in the R^b adjustment method estimated via bootstrapping resulted in CV's for the $R^b_{1,3}$ and $R^b_{2,5}$ estimates of 0.15 and 0.11 respectively, while the corresponding CV for the $R^b_{1,5}$ adjustment estimate was 0.24. These values were used in estimation of added variability associated with gear effects in the larval

Table 4. Results of the catch curve analysis for the 333 μm and 505 μm mesh sizes (Parameter estimates for the D variable represent the estimated Z)

333 Mesh analysis, (3 ≤ D ≤ 10)

Analysis of variance

Source	DF	Sum of squares	Mean square	F value	Prob > F
Model	1	1.66963	1.66963	122.899	0.0001
Error	6	0.08151	0.01359		
C total	7	1.75114			
Root MSE		0.11656	R-square		0.9535
Dep mean		2.76056			

Parameter estimates

Variable	DF	Parameter estimate	SE	T for H_0: Parameter = 0	Prob > |T|
INTERCEP	1	4.056539	0.12395302	32.726	0.0001
D	1	−0.199382	0.01798499	−11.086	0.0001

505 Mesh analysis (4 ≤ D ≤ 10)

Analysis of variance

Source	DF	Sum of squares	Mean square	F value	Prob > F
Model	1	1.18464	1.18464	383.258	0.0001
Error	5	0.01545	0.00309		
C total	6	1.20009			
Root MSE		0.05560	R-square		0.9871
Dep mean		2.86675			

Parameter estimates

Variable	DF	Parameter estimate	SE	T for H_0: Parameter = 0	Prob > |T|
INTERCEP	1	4.306580	0.07649022	56.302	0.0001
D	1	−0.205690	0.01050674	−19.577	0.0001

density estimates. An alternative to the age-based adjustment for gear selectivity applied in this analysis is a length-based estimate of larval loss. The sensitivity of the estimation to a length-based procedure for estimating larval loss due to differential gear selectivity needs to be examined in future applications of the index.

The four methods of calculating the annual larval index values did not give substantially different results (Fig. 6). Table 5 summarizes the larval survey data used for estimating annual index values, and gives the results of the four methods for estimation. The first method aged individual fish by the linear trend model in Table 1 and Figure 3. The second method aged individual fish with the P(D | l) matrix in Table 3. The third and fourth methods also used the P(D | l) matrix for ageing, but also incorporated the two gear efficiency adjustment methods described above. The larval survey index values estimated in the fashion described in this paper have been used by ICCAT Standing Committee on Research and Statistics for tuning the western Atlantic bluefin VPA since its 1989 meeting, generally scaling the annual index values to the maximum mean I in the time series. Prior to that an alternative formulation (McGowan and Richards, 1987) was used. We feel that the method incorporating the classification matrix ageing and adjustment by Z, although it does not appear to give different results from the other methods used in this paper, is the superior method of those tested (method d in Table 5; Fig. 6d) because it incorporates the most biological reality.

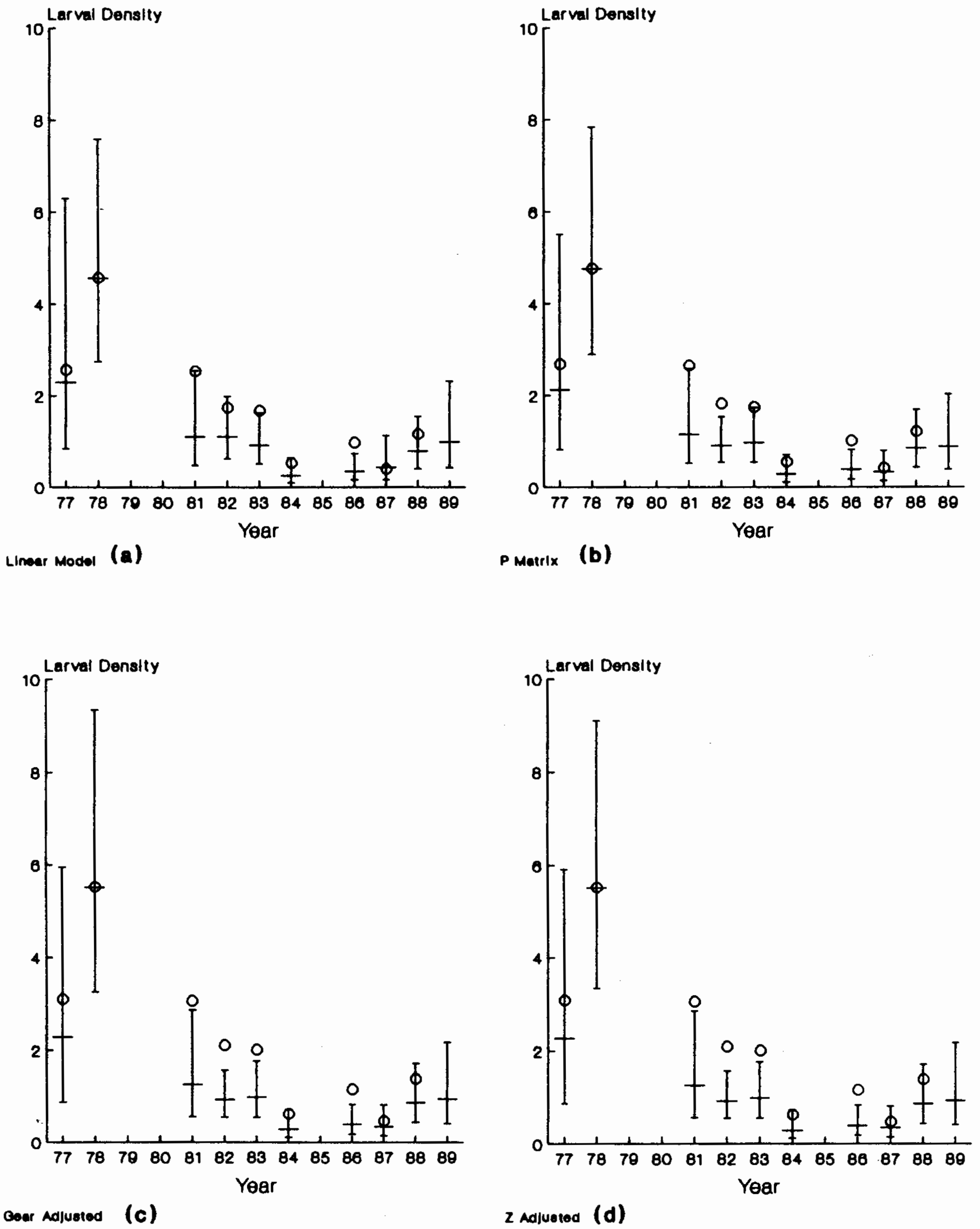


Figure 6. Bluefin tuna survey larval index values (bar) with associated 95% confidence regions based solely on estimated between station variability. Larval index values used by the 1989 SCRS Bluefin Tuna Species Group are shown with open circles. Upper left graph depicts method a in Table 5; upper right, method b; lower left, method c; and lower right, method d.

That is, the method includes the uncertainty in estimating age from length and adjusts for different gear efficiencies in the straightforward manner of backcalculating the abundance of partially recruited ages from the estimated Z value.

That there is a high level of uncertainty associated with the larval index is not unexpected because of the need to make assumptions about such characteristics

Table 5. Summary of the larval survey data used in estimating the annual larval index and associated variances (Four methods were used for estimation to test the sensitivity of the results to different assumptions)

	Year									
	1977	1978	1981	1982	1983	1984	1986	1987	1988	1989
Sampling date range	505–512	502–530	501–526	415–525	422–523	421–512	423–522	418–521	420–525	426–527
Stations sampled	20	74	32	121	94	74	73	77	78	72
Stations sampled with larvae	8	33	6	21	18	6	7	5	13	10
Total catch	22.	227.	20.	74.	74.	13.	12.	10.	64.	36.
Mean length of larvae	4.7	4.0	4.6	4.1	3.6	4.4	4.9	5.0	3.4	4.1
Length range of larvae	3.4–8.1	2.4–9.5	2.7–7.0	2.0–10.7	2.1–6.8	3.0–6.0	3.5–6.0	2.3–9.2	2.3–6.9	2.5–8.0
a: Aged by linear model										
Mean I (larvae/100 m^2)	2.288	4.562	1.099	1.101	0.908	0.251	0.337	0.433	0.777	0.984
Mean $\log_e(I_s)$	0.967	1.752	1.590	1.396	1.203	0.845	1.149	1.698	1.184	1.452
Variance ($\log_e(I_s)$)	1.927	1.260	0.441	0.968	0.763	0.708	0.253	0.515	0.789	1.176
Between station variance	1.605	1.452	0.245	0.115	0.077	0.016	0.018	0.050	0.078	0.199
b: Aged by P(D|l) matrix										
Mean I (larvae/100 m^2)	2.115	4.759	1.148	0.905	0.968	0.279	0.380	0.330	0.852	0.915
Mean $\log_e(I_s)$	1.017	1.793	1.677	1.346	1.272	0.951	1.270	1.547	1.280	1.410
Variance ($\log_e(I_s)$)	1.588	1.206	0.329	0.652	0.751	0.708	0.254	0.201	0.779	1.099
Between station variance	1.201	1.516	0.246	0.061	0.087	0.020	0.024	0.024	0.093	0.166
c: Adjusted by R^a method										
Mean I (larvae/100 m^2)	2.266	5.896	1.309	0.969	1.058	0.286	0.392	0.348	0.914	0.980
Mean $\log_e(I_s)$	1.088	1.975	1.806	1.396	1.350	0.972	1.300	1.672	1.360	1.455
Variance ($\log_e(I_s)$)	1.603	1.273	0.337	0.690	0.774	0.725	0.258	0.131	0.759	1.157
Between station variance	1.386	2.448	0.322	0.073	0.105	0.021	0.025	0.025	0.106	0.196
d: Adjusted by R^b method										
Mean I (larvae/100 m^2)	2.266	5.511	1.270	0.932	0.991	0.286	0.393	0.342	0.868	0.944
Mean $\log_e(I_s)$	1.088	1.931	1.777	1.373	1.292	0.972	1.300	1.577	1.297	1.439
Variance ($\log_e(I_s)$)	1.603	1.222	0.332	0.656	0.757	0.725	0.258	0.213	0.783	1.106
Between station variance	1.386	2.059	0.302	0.065	0.091	0.021	0.025	0.026	0.097	0.177

Notes: All indices except method a were aged using the classification matrix. Method a uses the linear model to predict age. No adjustments for potential gear effects were made in methods a and b. Adjustment factors for methods c and d are described in text. The Mean I represents the Δ-distribution value in arithmetic scale. Between variance implies variability between stations based on the Δ-distribution transform. All I values are in units of larvae at daily increment 1 per 100 m^2. Sampling dates are month and day.

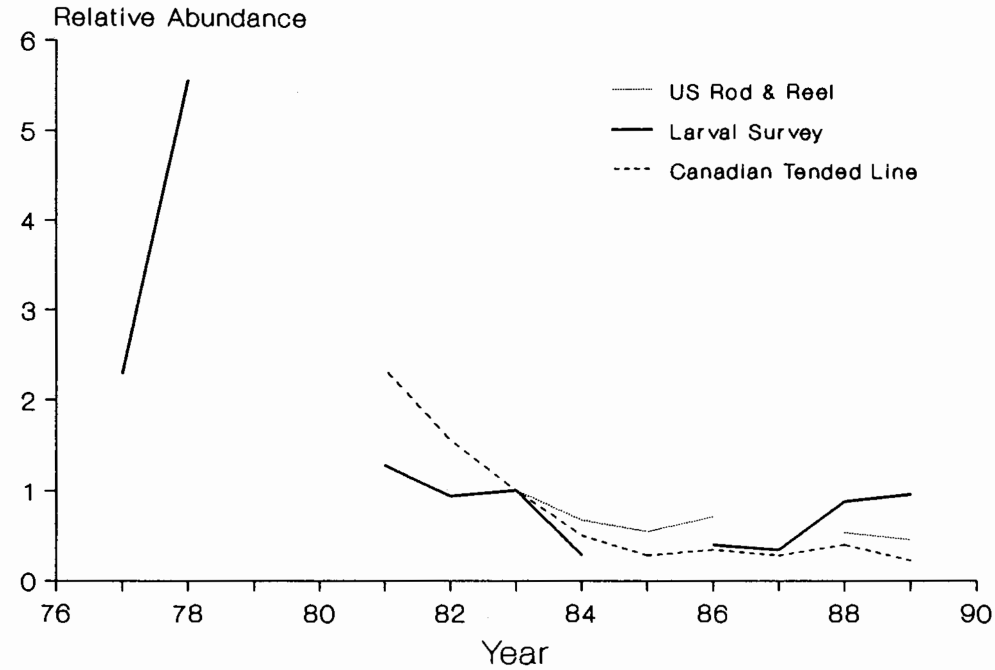


Figure 7. Three indices of abundance of large bluefin tuna in the western Atlantic Ocean scaled to their 1983 values. The three indices are: the larval index (method d in Table 5), an index from the rod and reel fishery off the northeast U.S. (Cramer and Brown, 1991) and an index from the Canadian tended line fishery (Clay et al., 1991).

as loss and growth rates, and because of the small numbers of larvae caught per year for the time series (10–27). One consequence of the high degree of variability in estimates of larval density when relatively few (i.e., 10 or fewer) larvae are sampled in the standard survey grid is that the statistical power for discriminating interannual differences in the index is low. Because of this, comparison of the mean values in isolation of their associated variances could lead to incorrect inference about change in the biomass that spawned the larvae. Alternative formulations of the index such as presence-absence estimation methods (Mangel and Smith, 1990) may provide more precise measures of spawning abundance. This method of estimation needs to be further investigated for bluefin tuna. However, even given the high degree of variability in the current index, ICCAT's SCRS has applied the index for calibrating (see discussion to follow) assessment analyses of western Atlantic bluefin stock status.

For the 1990 western Atlantic bluefin assessment, two other indices of abundance of large bluefin were available: the rod and reel fishery for large bluefin (>200 cm straight FL) off the northeast U.S. in 1983–1989 (Cramer and Brown, 1991) and the Canadian tended line fishery for even larger bluefin in 1981–1989 (Clay et al., 1991; Fig. 7). Comparison of these with the larval index shows that they follow a trend similar to larval index and each other. The annual mean index values from all three indicate relatively higher catch rates in the early 1980's than in later years, while the larval index mean values show a relative increase in the late 1980's not reflected in the other indices. Approximate confidence bounds estimated for the larval index (Fig. 6d) and the U.S. rod and reel index (Cramer and Brown, 1991), suggest that differences between index series in recent years are not statistically significant.

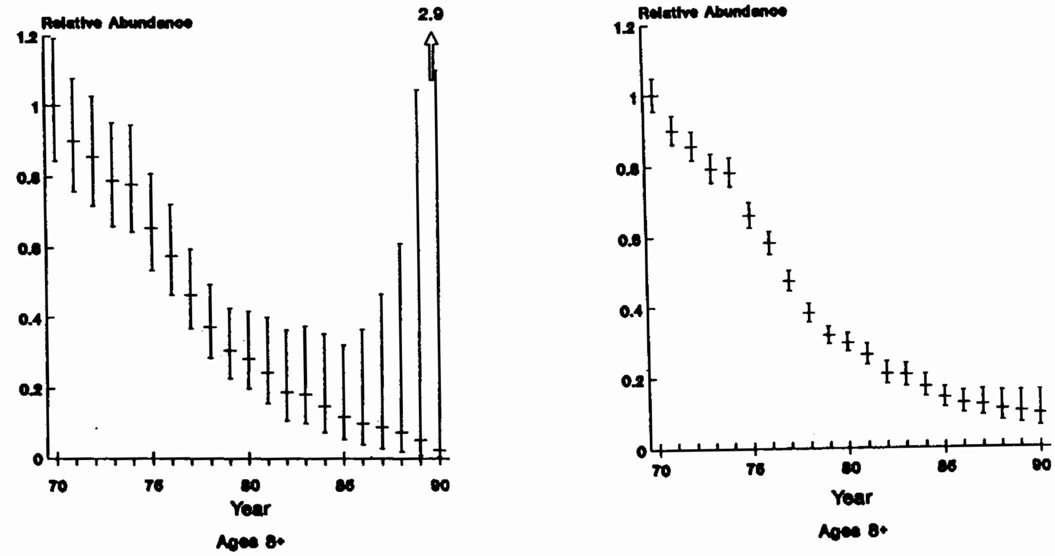


Figure 8. Relative abundance of western Atlantic bluefin tuna aged 8 years and older from 1970–1990 as estimated by VPA calibrated with the larval index (graph on left) and with all 6 available indices (graph on right, Anon., 1991). Estimated abundance of large (ages 8+) west Atlantic bluefin tuna resulting from VPA were tuned to index mean values. Depicted are stock size esimates relative to the 1970 estimated abundance and the associated 95% confidence regions estimated by the delta method.

ICCAT assessment working groups have used a larval index to identify trends in the abundance of large bluefin tuna in the western Atlantic Ocean. That the index is fishery independent and based on the results of spawning in the Gulf of Mexico is useful because other indices available for large bluefin in the western Atlantic are derived from fishery data which could conceivably include catches of fish which had migrated from the eastern Atlantic.

Indices of abundance have been used to calibrate VPA's of bluefin and other species (Parrack, 1986; Gavaris, 1988; Conser and Powers, 1990). The indices are used to determine the most likely population trend from the wide range of trends that can be estimated from the catch at age. Scientists from ICCAT member nations calibrate bluefin tuna VPA's using multiple indices of abundance, including the larval index. When the larval index is the only index used to calibrate the VPA, conditional confidence intervals (considered conditional because they are dependent on assumptions built into the VPA, including assumed natural mortality rate, that the mean index values are measured without error, and that the population dynamics are captured by the process implicit in the VPA model applied) about estimates of population size for the ages expected to spawn in the Gulf of Mexico (ages 8 years and older) are wide (Fig. 8), and increasingly so in recent years. This results from the relatively poor fit between the VPA and the larval index. Narrower confidence intervals about estimated stock size are obtained when the VPA is tuned with several other indices of abundance (e.g., U.S. rod and reel and Canadian tended line indices; Fig. 8), resulting in less confidence in the larval index as a precise indicator of interannual change in stock biomass.

Acknowledgments

This manuscript was prepared in support of a presentation of the research described herein at the American Fisheries Society Early Life History Section Symposium on Biomass Estimation of Fish

Stocks using Ichthyoplankton, held at the National History Museum of Los Angeles County from 22–26 June 1991. The manuscript has been substantially improved, largely through critical reviews of earlier drafts. The authors thank Drs. N. C. Lo, J. Hunter, J. Powers, B. Brown and two anonymous reviewers for their efforts in this regard. This manuscript represents contribution MIA-90/91–61 from the National Marine Fisheries Service, Southeast Fisheries Science Center, Miami Laboratory.

Literature Cited

Anonymous. 1991. ICCAT SCRS report for the biennial period 1990–91. Part II (1990). Int. Comm. Conserv. Atl. Tunas.

Brothers, E. B., E. D. Prince and D. W. Lee. 1983. Age and growth of young-of-the-year bluefin tuna, *Thunnus thynnus,* from otolith microstructure. Pages 49–60 *in* E. D. Prince and L. M. Pulos, eds. Proceedings of the international workshop on age determination of oceanic pelagic fishes: tunas, billfishes, and sharks. NOAA Tech. Rep. NMFS 8. 211 pp.

Clay, D., T. Hurlbut and J. M. Porter. 1991. National report of Canada. Report for the biennial period 1990–91. Part I (1990). Int. Comm. Conserv. Atl. Tunas. Pp. 412–418.

Collette, B. B. and C. E. Nauen. 1983. Scombrids of the world. FAO, Fish. Syn. 125(2): 137 pp.

Conser, R. J. and J. E. Powers. 1990. Extensions of the ADAPT VPA tuning method designed to facilitate assessment work on tuna and swordfish stocks. ICCAT. Col. Vol. Sci. Pap. 32(2): 461–468.

Cramer, J. and C. A. Brown. 1991. Standardized catch rates of large bluefin tuna in the New England (U.S.) rod and reel/handline fishery. ICCAT. Col. Vol. Sci. Pap. 35(2).

Gavaris, S. 1988. An adaptive framework for the estimation of population size. Can. Atl. Fish. Soc. Adv. Comm. (CAFSAC) Res. Doc. 88/29. 12 pp.

Houde, E. D. 1989. Comparative growth, mortality, and energetics of marine fish larvae; temperature and implied latitudinal effects. Fish. Bull. U.S. 87: 471–495.

Mangel, M. and P. E. Smith. 1990. Presence-absence sampling for fisheries management. Can. J. Fish. Aquat. Sci. 47: 1875–1887.

McGowan, M. F. and W. J. Richards. 1986. Distribution and abundance of bluefin tuna (*Thunnus thynnus*) larvae in the Gulf of Mexico in 1982 and 1983 with estimates of the biomass and population size of the spawning stock for 1977, 1978, and 1981–1983. ICCAT. Col. Vol. Sci. Pap. 24: 182–195.

——— and ———. 1987. Atlantic bluefin tuna spawning and larval index of spawning stock 1977–1986. University of Miami, Rosenstiel School of Marine and Atmospheric Science, TR-88-003. 12 pp.

Murphy, G. I. 1990. A review of Atlantic bluefin tuna larval surveys. ICCAT. Col. Vol. Sci. Pap. 32(2): 262–269.

Parrack, M. L. 1986. A method of analyzing catches and abundance indices from a fishery. ICCAT. Col. Vol. Sci. Pap. 24: 209–221.

Pennington, M. 1983. Efficient estimators of abundance for fish and plankton surveys. Biometrics 39: 281–286.

Richards, W. J. 1990. Results of a review of the U.S. bluefin tuna larval assessment with a brief response. ICCAT. Col. Vol. Sci. Pap. 32(2): 240–247.

——— and T. Potthoff. 1980. Distribution and abundance of bluefin tuna larvae in the Gulf of Mexico in 1977 and 1978. ICCAT. Col. Vol. Sci. Pap. 9(2): 433–441.

Seber, G. A. F. 1983. The estimation of animal abundance, 2nd ed. Macmillan Publ. Co. Inc., New York. 654 pp.

Date Accepted: April 28, 1993.

Addresses: *(G.P.S., S.C.T., W.J.R.) National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Southeast Fisheries Center, Miami Laboratory, 75 Virginia Beach Drive, Miami, Florida 33149; (C.B.G.) Panama City Laboratory, 3500 Delwood Beach Road, Panama City, Florida 32407; (E.B.B.) EFS Consultants, 3 Sunset West, Ithaca, New York 14850.*